Overview of R&D Activities for BNL EIC

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EIC Accelerator Collaboration Meeting

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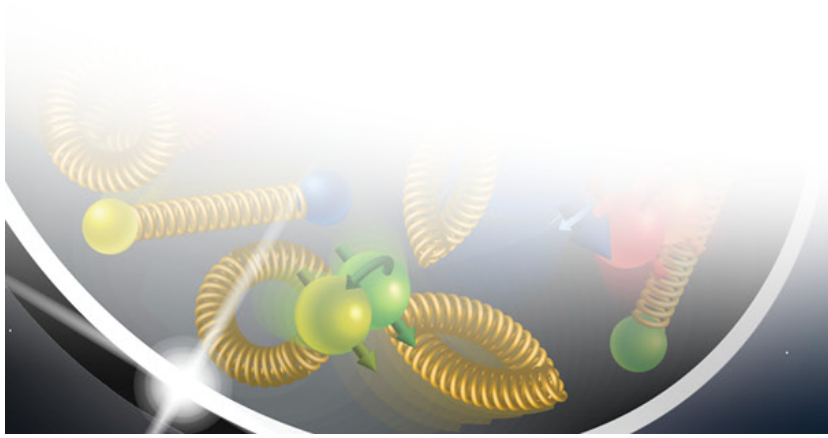
Electron Ion Collider – EIC at BNL

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Overview

- eRHIC R&D overview
- Status of R&D in various technological areas
- Summary



eRHIC R&D Overview

eRHIC R&D program includes following elements:

- Development of pre-conceptual Design **(accomplished)**
- Development of beam dynamics models and simulation codes for EIC
- Development of reliable electron and ion sources
  - High charge polarized photo-cathode gun
  - High current unpolarized photo-cathode gun for cooling ERL
  - Polarized He3 source
- Superconducting RF R&D for EIC
  - Five cell s.c. cavity development for cooling ERL and RCS
  - eSR cavity development
  - High power (500kW) main forward coupler with variable coupling development
  - Test of Si-C HOM absorber
  - Crab-Cavity prototype beam test at CERN SPS, evaluation of results
- Strong Hadron Cooling
  - Development of 3-D μ–bunched electron beam cooling theory @ simulation, strawman design of cooling facility
  - Experimental tests at RHIC
  - Explore storage ring based incoherent electron cooling
- SC-IR quadrupole development
  - Prototyping of Nb-Sn IR quadrupole
  - Exploring high-field limit of direct wind s.c. IR magnets
  - Double-helix tapered magnet technology

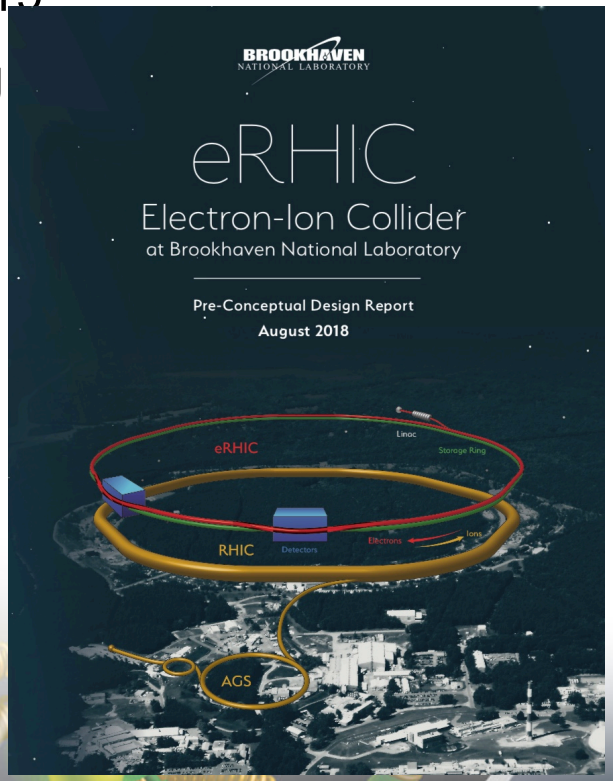
Supported by different funding sources: DOE FOA, LDRD, PD funds, and others

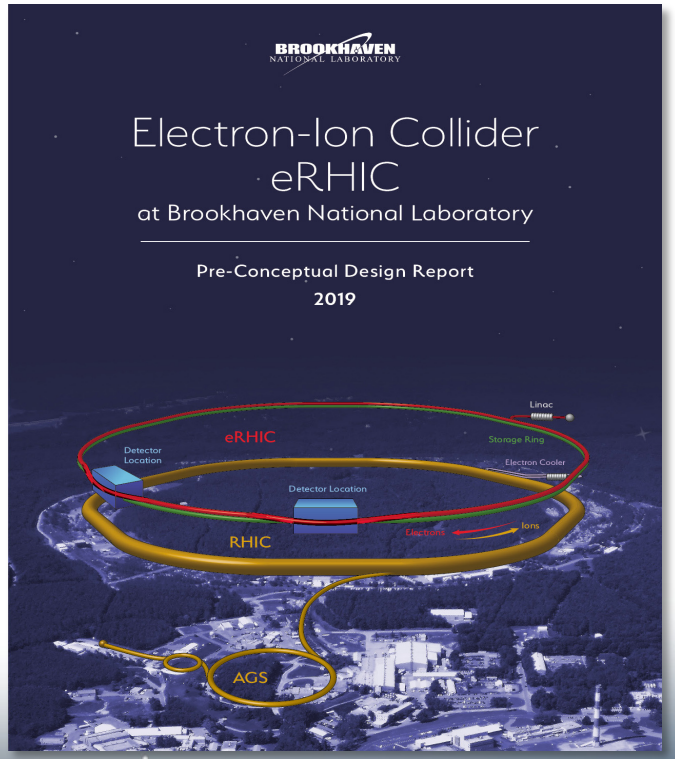
eRHIC Development and Design Studies

Goal: Develop low risk Ring-Ring based BNL EIC which demonstrates EIC design goals, resolves beam dynamics questions and issues, and remains within cost expectations

Result: Comprehensive pre-conceptual design report completed in July 2018, updated August 2019, Preconceptual Design Review by top authorities of the field April 2018/2019

Funding





eRHIC Beam Dynamic Studies and Development of Simulation codes

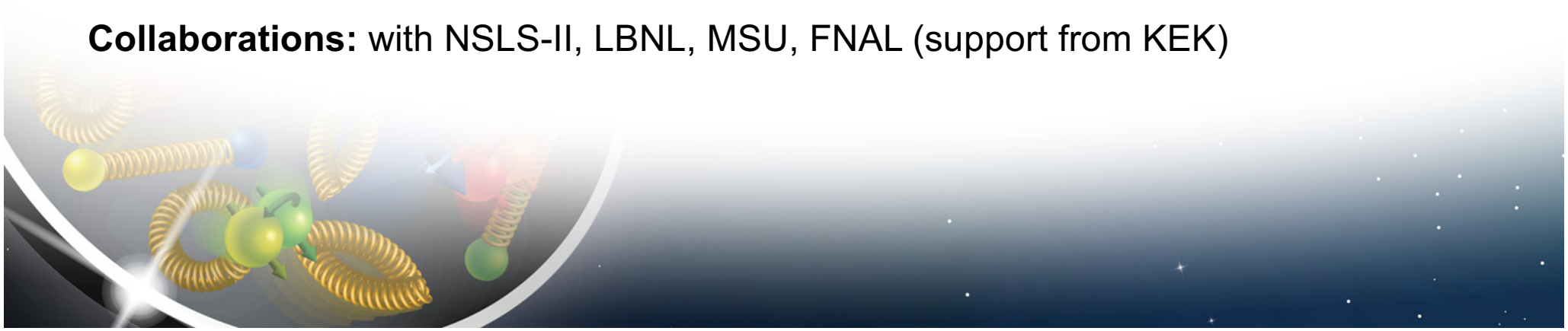
Goal: Develop/adapt computer code for critical EIC beam dynamics issues, benchmark codes by comparing different codes and by comparing simulations with experimental results

Result: Computer codes for all critical beam dynamics issues made available (beam-beam effects, dynamic aperture, polarization, fast ion instability, electron cloud effects, collective effects, Intrabeam-Scattering …) compared to each other, whenever possible compared with experiments. Critical simulations carried out in support of eRHIC design study

Ongoing: Continue on critical beam dynamics questions (crab crossing, fast ion instability, electron cloud instability (plus specific R&D topics discussed below)

Funding: Base Funding FY17-18, LDRD FY16-17, Additional NP funding KB020105-2, FOA FY18-19 (beam-beam centered)

Collaborations: with NSLS-II, LBNL, MSU, FNAL (support from KEK)



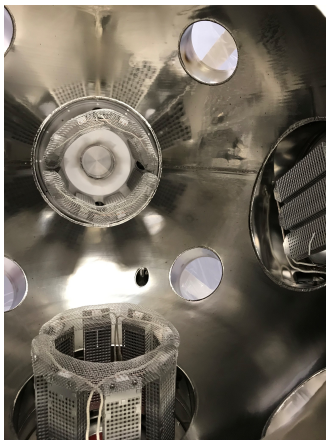
eRHIC Development of Polarized Electron Guns

Goal: - Develop polarized electron gun for high bunch charge (>15 nC), high average current (>50 mA@ 5nC), high reliability, and long cathode lifetime

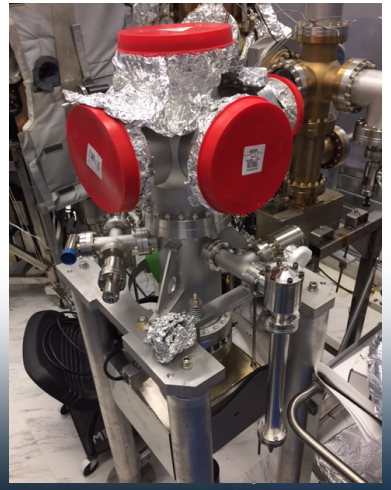
Funding: Base Funding FY17-18, Additional NP funding FY17/18, HEP-DD funds, BNL Program Development Funds (PDF).

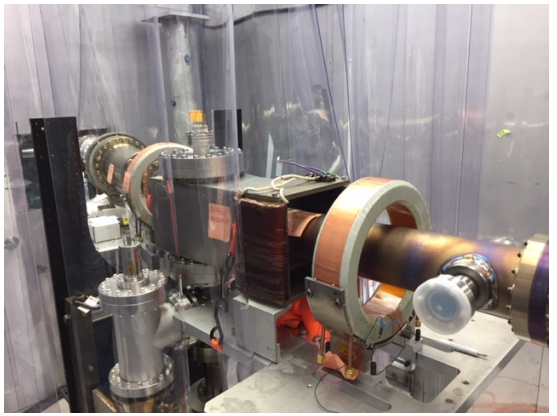
Collaborations: MIT, TJNAF

Gun Insulator and feedthrouh



Neg Modules and Ion Pumps





Diagnostic beam line

New Cathode Storage Chamber

eRHIC Prototype Electron Source and Diagnostic Beam line nearing completion at Stony Brook University

Results: -Diagnostic beamline designed, assembled, vacuum tested

-New inverted gun design with minimum ion back-bombardment

-Parts for new gun procured, prepared, assembly started

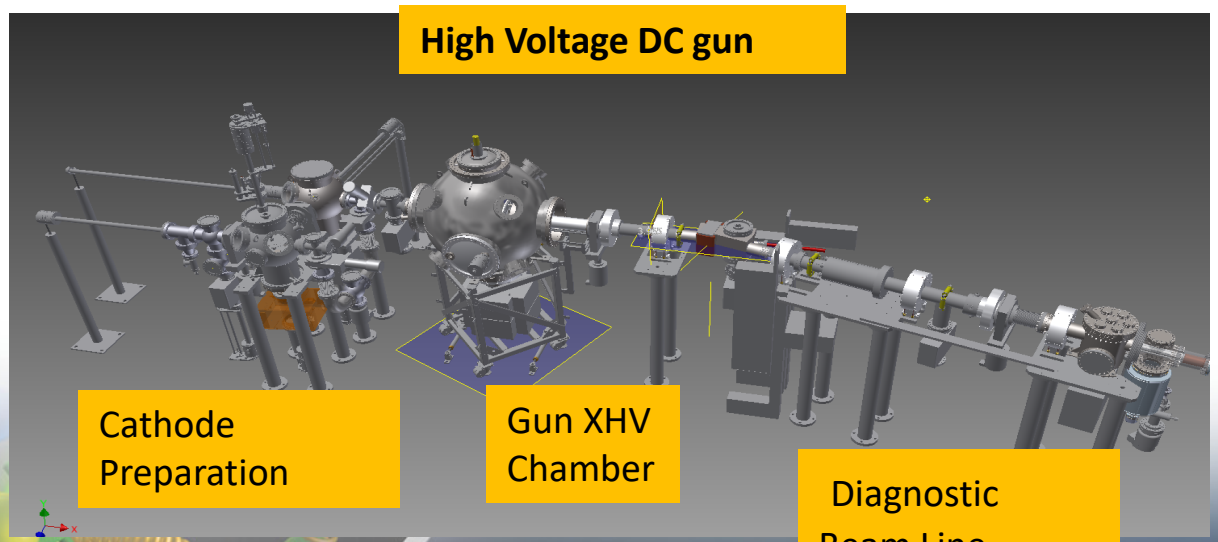
- High voltage bench tested up to 410 kV

-Gun chamber ready for high T bake out

-Gun Drive lasers (Green and IR) are complete and under test; laser beam transport has been established

-Vacuum tests underway

Next steps: complete assembly and start beam tests; prepare e-source lab at BNL



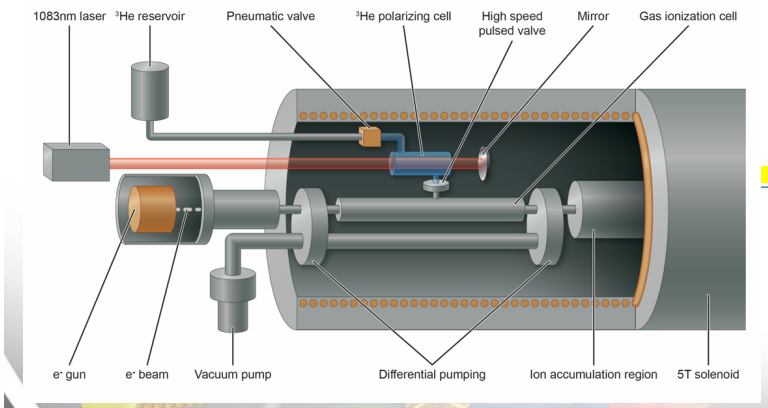
R&D on polarized 3He++ Source

Goals: a)Demonstrate generation of polarized 3He++;
Intensity 2.5 × 10^{11} ^{3}He++ ions in 20 μs pulse (~4 mA peak current)
b) Develop 3He++ polarimeter (BNL medium energy group)

Results: a) Polarized 3He gas with polarization of >80% in 3T field achieved
b) All parts needed for integration into EBIS received or on order
c) The ^{3}He spin-rotator is being designed and equipment purchased.
d) The 6 MeV ^{3}He polarimeter has been designed and the concept was tested with an alpha source.

Next steps: partial installation in the summer of 2020 and complete installation followed by polarization measurements in the summer of 2021.

Funding: Base Funding FY17, Additional NP funding FY17, NP FOA FY18/19



EBIS Solenoids

Superconducting RF R&D for BNL-EIC

Goals: Develop RF technology to identify unexpected challenges and to verify assumptions for the accelerator development.

This includes:
- Develop of superconducting (s.c.) cavities for ERL application (strong hadron cooling),
- Electron ring storage ring cavity development,
- Development of high power (0.5MW), variable coupling FPC
- R&D on performance and manufacturability of SiC beam pipe absorber
- Analysis of at from crab-cavity beam test at CERN SPS (**Coll JLAB)**

Results: - 5-cell high current Linac cavity developed and prototyped in industry (Cu and Nb units, vertically cold tested, calculated HOM verified

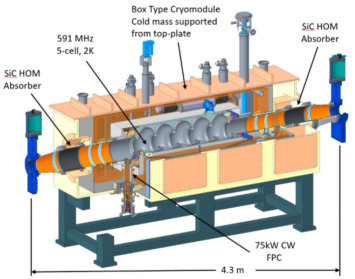
- 2-cell sc storage ring cavity developed with appropriate HOM damping which satisfies storage ring power and voltage needs and beam stability requirement

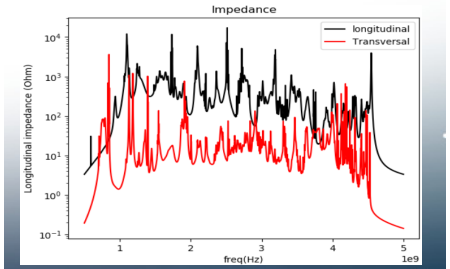
Funding: LDRD FY16-19, Base funding FY17/19

SiC HOM absorber

FPC components

ERL and RCS Cavity, HOM structure





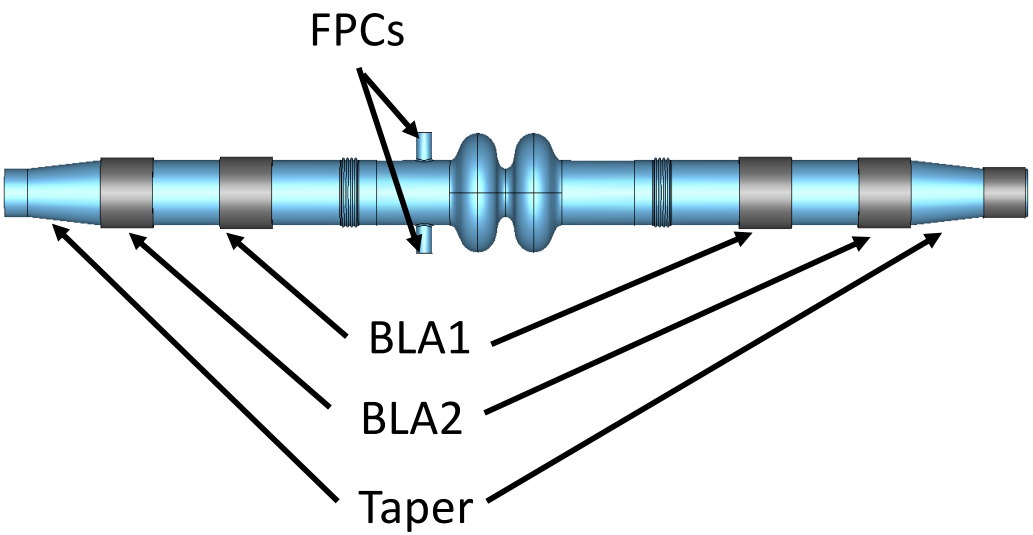
Tunable High Power FPC for storage SRF cavity

-FPC design follows experience from previously built 1MW FPC
-Q_{ext} variable by order of magnitude
-All components manufactured, test stand built for high power tests
-FPCs is undergoing bakeout and vacuum leak testing
-FPC conditioning in high power test line starts later in October

adjustable waveguide tuner

FPC conditioning waveguide setup for high power test

SiC HOM Absorbers



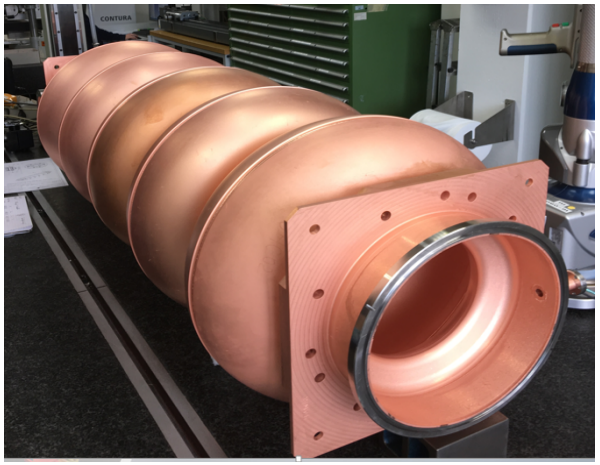
Fabricated SiC absorber cylinder

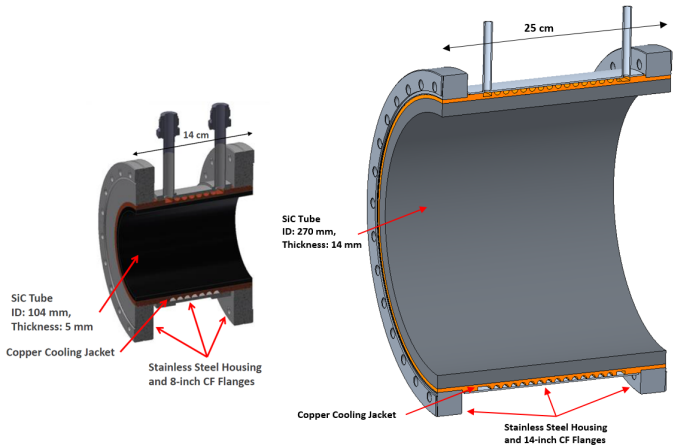
SiC sample outgassing measurement setup

- HOM damper design results meet the limit set by beam instability, and with reasonable HOM power (80 kW per cavity).
- The RF design of the HOM absorber was completed in the pCDR study.
- Two sets of room temperature SiC BLAs are optimized to damped all the HOMs.

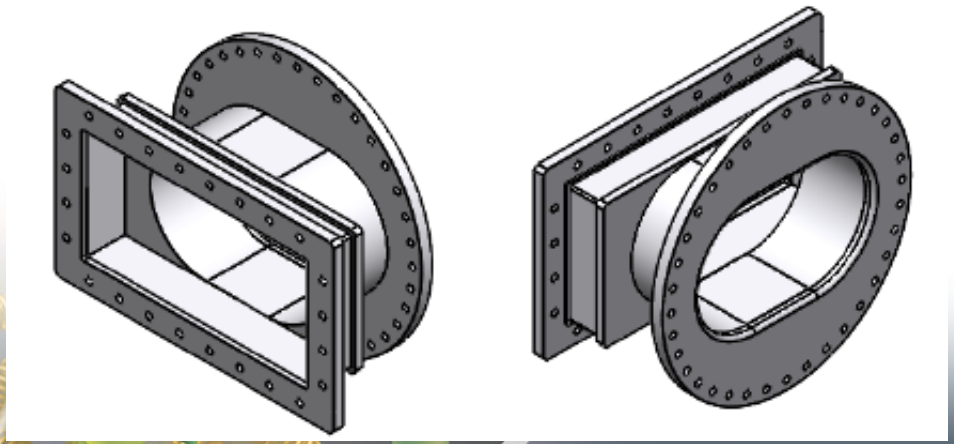
High power and low power RF tests of SiC absorber

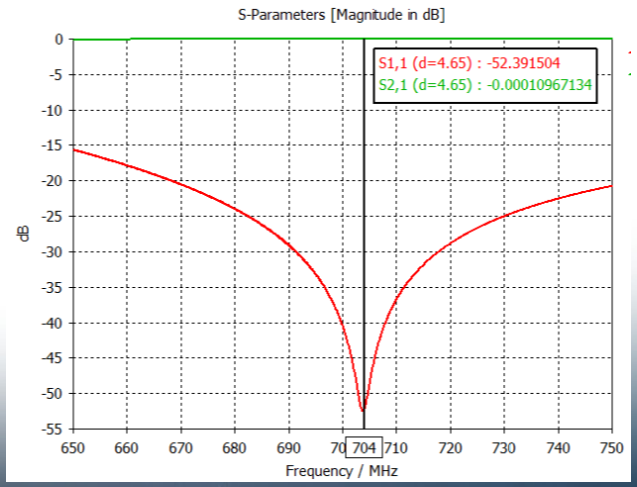
- Low power RF test: to test the HOM damping effects on existing 650 MHz cavity.





- High power test: to test the power handle capabilities (thermal) with an existing 704 MHz RF source in the building 912 RF test facility.





R&D on Advanced Hadron Cooling

Goals: a) Develop theory and simulation models for micro-bunched coherent electron cooling

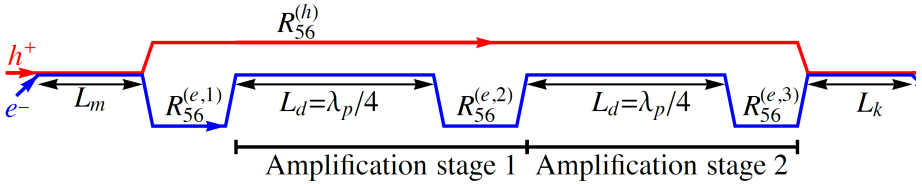
b) Demonstrate coherent electron cooling in PoP experiment

Results a): theory developed for 3-D cooling of flat hadron beam by short electron bunches, theoretical model confirmed by simulation (in progress), Strawman of cooling facility developed, low energy electron beam transport optimized

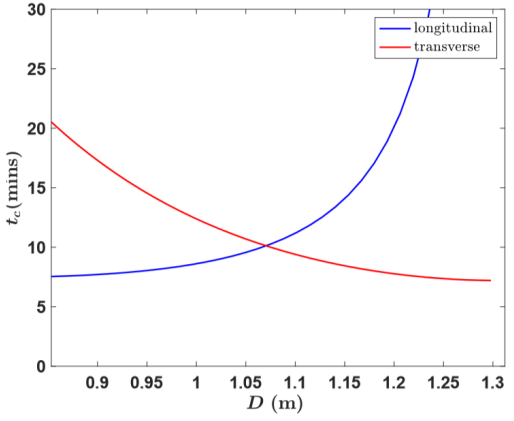
Ongoing: Develop cooling model including a full 3D dynamical model of hadrons and electrons, study role of wigglers in amplification section

Funding: NP FOA funding FY18/19, BNL PD

Collaborations: SLAC, TJNAF, ANL



μ-bunched electron cooling:
Optimization of dispersion to balance transverse vs longitudinal cooling times



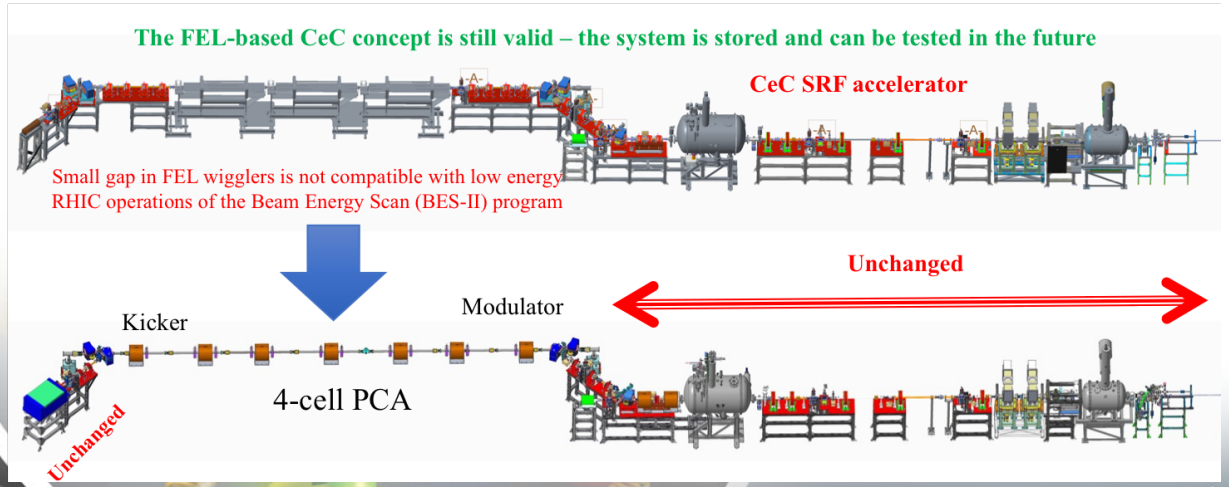
Wigglers in amplification section should shorten the required space

CeC PoP Experiment in RHIC

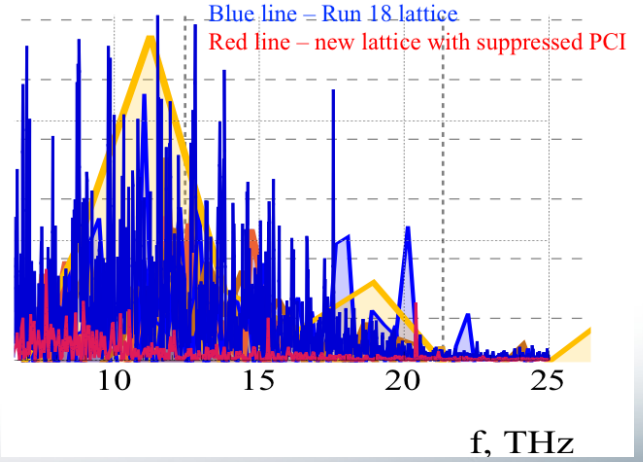
Results: -CeC SRF accelerator has been fully commissioned
-Electron beam noise problem in Run-18. Noise enhancement by transport line optics was identified and explained: Plasma Cascade Instability.
- Run-19: demonstrated acceptable level of the electron noise control

Next steps: Changing CeC amplifier from FEL to PCA (Plasma Cascade Amplification);
Demonstrate PCA; Observe ion imprint in the electron beam;

Change of amplification scheme: to be completed this year



Electron noise level improvements



Incoherent Electron Cooling with Electron Ring

Goals: Develop the concept of electron ring based incoherent electron cooling for eRHIC

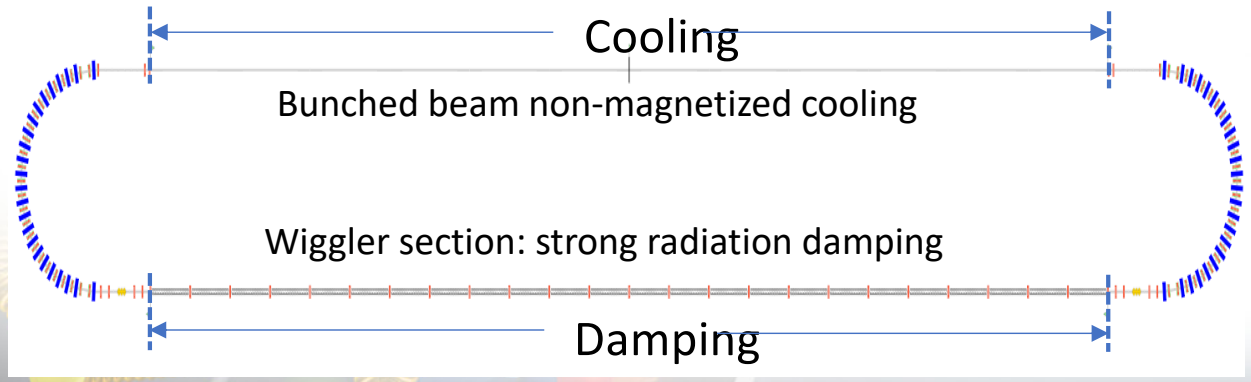
Results: - A preliminary ring-based cooler was designed

-Demonstrated sufficient cooling power to maintain 4.3E33 luminosity level for operation with 275 GeV protons

Next steps: Optimization of the optics design, improving DA.

Funding: FY18/19 FOA

Collaborations: TJNAF



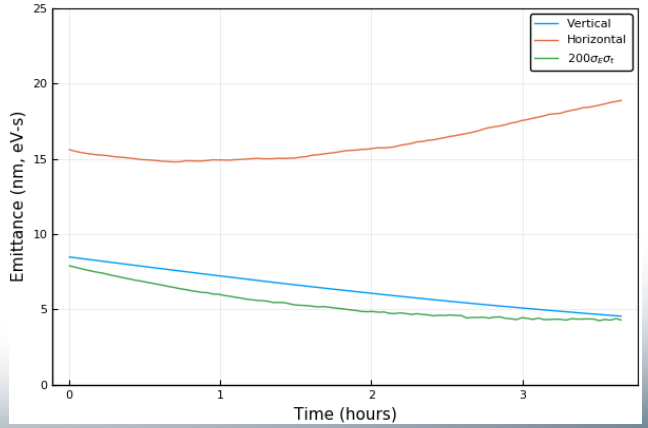
Cooler-2 (H&V-Wiggler)

ε_x=26nm, ε_y=14.7nm

dp/p=0.725e-3

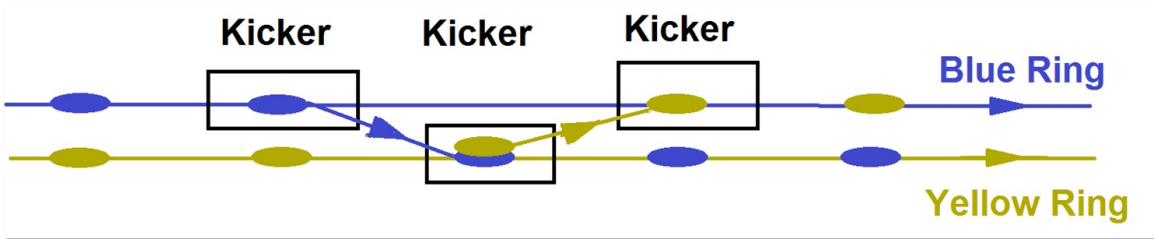
length=0.1m

N=3e11



Alternative to Strong Hadron Cooling

- Since present RHIC has a second superconducting ring, the Blue Ring, on-energy injections into the collider ring, the Yellow Ring will replace the hadron bunches after one hour of storage.
- Transfer takes 13 μs and will preserve the total charge in both machines, no transient injection effect.



- The average luminosity of ~$0.9 \cdot 10^{34}$ $cm^{-2}s^{-1}$ can be maintained.
- For maximum luminosity a pre-cooler at low energy is needed: ERL-based electron cooler at injection energy (25 GeV) and/or standard DC electron cooler in the AGS.

Next steps: Developing details of Blue ring by-passes in detector areas and the pre-cooler scheme. Better assessment of the scheme cost.

R&D on EIC IR magnets

Goals: -Demonstrate feasibility a Nb-Sn based IR quadrupole by building a magnet using

an existing coil (from LARP),

-Explore helical direct wind and high field capability of direct wind

Results: mechanical magnet design and cryostat complete, NbSn coil tested

Tilted direct wind coil in progress

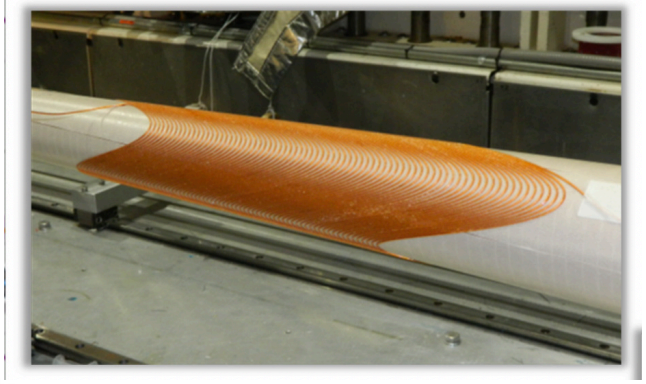
Next step: Assembly and test

Funding: Base Funding FY17/18

Additional NP funding FY17, FY18/19 FOA, LARP

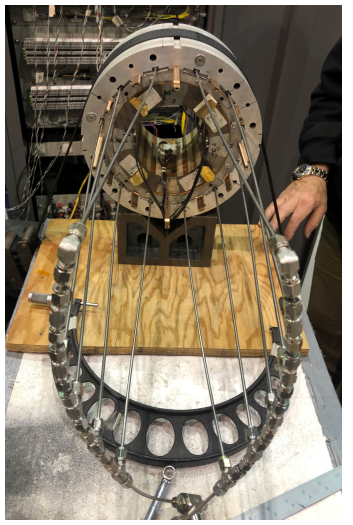
Collaborations: TJNAF, LBNL

Tilted direct wind coil



Constant gradient tapered quadrupole (to pass synrad cleanly in rear side electron magnets)

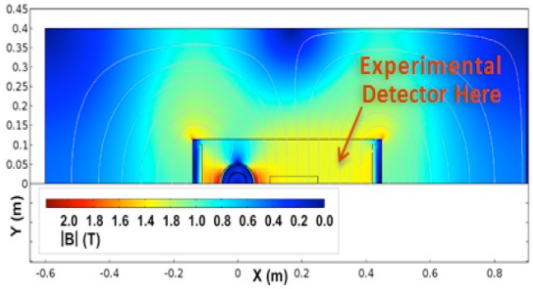
Short Nb_3-Sn Test coil

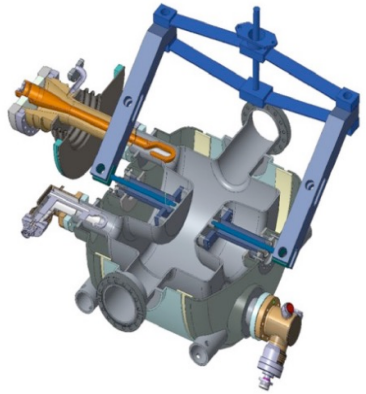


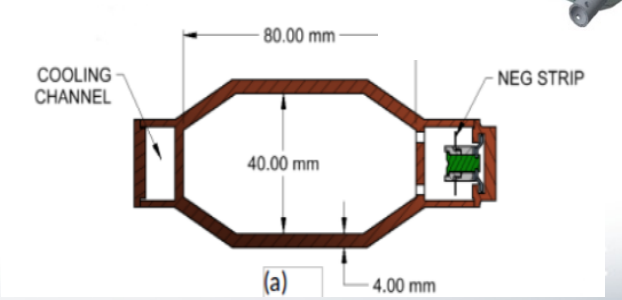
But latest versions of IR designs (in both eRHIC and JLEIC) does not require Nb_3Sn magnets

Preliminary scope of on-project R&D has been defined

- IR Magnet Prototyping
- Critical Cryomodule Component R&D
- Proton Injection & eSR Extraction Kickers
- eSR Cavity Prototype
- Crab Cavity Prototype
- eSR & Detector Interface Vacuum Systems







All work will finish before CD3.

Summary

- Comprehensive R&D efforts lay the foundation of the BNL-EIC development
- Pre-conceptual layout meets or even exceeds all requirements of LRP
- The pre-conceptual design based on many decades of experience of working with colliders, is mature for the present stage (pre-CD0) and meets or even exceeds all requirements of LRP
- On-going R&D efforts address important technologies used in the pre-conceptual design: polarized sources, various technological aspects of SRF, strong hadron cooling, IR magnets
- Preliminary scope of on-project R&D has been established.